Deformation Mechanisms of Ferrite-martensite Dual Phase Steel with Nano-precipitation

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論文内容要約

Chapter 1: Introduction

Ferrite-martensite dual phase (DP) steels, composed of soft ferrite and hard martensite phases, are known to have a good combination of high strength and excellent stretchability. Stress-strain curves of DP steels are characteristics by low yield stress accompanied by continuous yielding, high work hardening rate, low yield ratio, large uniform elongation, but limited post-uniform elongation. In contrast, single phase ferrite steel, with a dispersion of nano-sized alloy carbides in ferrite phase are well known as interphase-precipitated steels, show both high strength and good stretch flangeability. Stress-strain curves of interphase-precipitated steels are characterized by high yield stress, low work hardening rate, high yield ratio, relatively small uniform elongation, but large post-uniform elongation. It is interesting to note that DP steels and interphase-precipitated ferrite steels have both advantages and disadvantages in their stress-strain behavior. It might be possible to improve the mechanical properties of DP steels by having a dispersion of alloy carbides in the ferrite phase of DP steels (i.e nano-precipitated DP steels), where the disadvantages of DP steels are compensated by the advantages of interphase-precipitated ferrite steels, and vice versa. This idea has been proposed previously and applied commercially for wheel discs of automobiles. But, deformation mechanisms of these steels are not yet understood well. In order to understand the deformation mechanisms of these nano-precipitated DP steels, the effect of various structural factors such as constituent ferrite/martensite phase volume fraction, distribution, size and strength on mechanical properties has to be systematically investigated. Thus, in the present study, the effect of following structural parameters, namely, (i) effect of ferrite/martensite volume fraction, (ii) effect of ferrite/martensite size and (iii) effect of ferrite/martensite strength on tensile behavior ferrite-martensite DP steels with interphase precipitated nano-sized vanadium carbides(VC) are investigated to understand the deformation mechanism.

Chapter 2: Experimental

Two categories of steels namely V-free (0.004C, 0.025C, 0.05C, 0.075C, 0.1C and 0.2C) and V-added steel (0.1C-0.4V and 0.2C-0.9V) were used to produce DP steels. The V-free steels were used to produce DP steel without dispersion of VC particles and V-added steel is used to produce DP steel with a dispersion of VC carbides through interphase precipitation in the ferrite phase. Microstructures were characterized by optical microscopy, scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The hardness of ferrite-martensite DP structures, the individual hardness of the ferrite phase, and martensite phase was measured using a Vickers hardness tester. Stress-strain curves were determined by a uniaxial tensile test at room temperature at an initial strain rate of 8.3×10^{-4} s^{-1}. The local deformation behavior of individual ferrite and martensite phase was quantified by digital image correlation (DIC) techniques. Further, the fracture behavior of the DP steels was also studied interms of void evolutions and local deformation behavior in necking region.

Chapter 3: Effect of phase volume fraction on the tensile behavior of nano-precipitated ferrite-martensite dual phase steels

In this chapter, effect of phase volume fraction on the tensile behavior of nano-precipitated DP steels was investigated. Two categories of steels namely V-free (0.004C, 0.025C, 0.05C, 0.075C and 0.1C) and V-added steel (0.1C-0.4V) were used to produce DP steels with different phase volume fraction. It was found that dispersion of nano-VC precipitates in ferrite leads to a significant increase in strength in DP steels. It should be emphasized that this strength increase occurs with almost no loss of both uniform and total elongation for ferrite volume fractions of 20-50%, while the uniform and total elongation becomes larger in the V-free steels compared to the V-added steels for ferrite volume fractions higher than 50%. The strength-elongation plots revealed that there is no significant difference in the strength-uniform elongation balance between V-free and V-added steels, but the strength-post uniform elongation balance, strength-reduction in area is greatly improved by dispersion of nano-VC precipitates. The DIC analysis of in-situ tensile tests demonstrates that deformation is more localized in soft ferrite than in hard martensite phase for both V-free and V-added DP steels, i.e. the strain partitioning between the ferrite and martensite phases is clearly observed. However, precipitation strengthening of ferrite by dispersion of nano-VC precipitates results in a decreased extent of strain partitioning. Further, law of mixtures can reasonably explain the flow stress-strain relationship of DP steels when the strain/stress partitioning estimated from the DIC analysis is considered.

Chapter 4: Effect of phase size on tensile behavior of nano-precipitated ferrite-martensite dual phase steels

In this chapter, effect of phase size on tensile behavior of nano-precipitated DP steels in comparison with conventional DP steels was investigated. Low carbon steels having compositions of Fe-0.049C-1.48Mn (V-free), and Fe-0.097C-1.49Mn-0.43V (V-added) were used. The thermo-mechanical treatments were optimized to obtain DP steels with ferrite volume fraction of about 50%, with different constituents phase size. In V-free DP steels, decrease in ferrite grain size (39 μm to 12 μm) hardly affects the strength while in V-added DP steels decrease in ferrite grain size slightly increase the strength. On the other hand, the total elongation especially the post uniform elongations and reduction in the area are greatly improved by refinement of constituent phase size in both V-free and V-added DP steels. Local deformation of individual ferrite and martensite phase becomes more homogeneous both in the work hardening region and necking region with a decrease in phase size, which eventually increase the post-uniform elongation of the DP samples. Quantitative examination of void observation shows that fracture by martensite cracking is the primary fracture mechanism in coarse DP steels, whereas ferrite/martensite decohesion becomes a dominant fracture mechanism in fine DP steels. Thus, the combination of fine phase size and dispersion of nano-precipitates in the ferrite phase are a promising strategy to improve the strength and strength-ductility balance in DP steels.

Chapter 5: Effect of phase strength on tensile behavior of nano-precipitated ferrite-martensite dual phase steels

In this chapter, the effect of phase strength on tensile behavior of nano-precipitated DP steels was investigated. A series of low carbon steel having compositions of Fe-0.049C-1.48Mn (V-free 0.05C), Fe-0.098C-1.50Mn (V-free 0.1C), Fe-0.02C-1.50Mn (V-free 0.2C), Fe-0.097C-1.49Mn-0.43V (V-added 0.1C) and Fe-0.19C-1.50Mn-0.87V (V-added 0.2C) were used. The thermo-mechanical treatments were optimized to obtain DP steels with ferrite volume fraction of about 50% and the ferrite grain size between 2.9-13 μm. The martensite phase strength was controlled by changing the carbon content in martensite and its tempering treatment, while ferrite strength of the DP structures was controlled by changing the volume fraction of VC particles precipitated in ferrite phase. It was found that strengthening of martensite phase, is an effective strategy to improve the strength and strength-uniform elongation balance of DP steels, On the other hand, strengthening of the ferrite phase by nano-sized alloy carbides for constant martensite strength is an effective strategy to increase strength, strength-post uniform elongation balance and strength-reduction in area balance. Strain partitioning between ferrite and martensite is suppressed by decreasing the phase strength difference, thereby homogeneous deformation is enhanced. Such tendency presumably remains even in the necking region leading to large post-uniform elongation. Ferrite/martensite decohesion is dominant fracture mechanisms irrespective of phase strength differences. Further, decreasing in phase strength difference suppress the strain required for void formation and number density of voids increases gradually, leading to large post-uniform elongation

Chapter 6: Conclusion

In the present study, the effect of structural parameters, namely constituent ferrite/martensite phase volume fraction, size and strength on the tensile behavior of ferrite-martensite dual phase (DP) steels with a dispersion of VC particles have been evaluated systematically in comparison with conventional ferrite-martensite DP steels without dispersion of nano-VC precipitates. The overall strategies to control the tensile properties of ferrite-martensite DP steels and by main findings of the present study are summarized.